NASA-CR-197143

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VII. PROGRESS REPORT

NASA Grant NAG 9-45

TITLE: Shock and Thermal History of Iron and Chondritic Meteorites

PRINCIPAL INVESTIGATOR: Dr. Joseph I. Goldstein (3/28/91)

This progress report includes our work since the last progress report of 3/31/90. Copies of the publications are attached to this proposal. Within this time period, we have had 3 papers published and 1 paper accepted for publication. Within the last two years we have had 11 papers published.

<u>The published papers are:</u>

1. "Electron Microscopy Study of the Iron Meteorite Santa Catharina", J. Zhang, D. B. Williams, J. I. Goldstein and R. S. Clarke, Jr., Meteoritics, <u>25</u> (1990), p. 167.

2. "Spatial Resolution and Detectability Limits in Thin-Film X-ray Microanalysis", J. I. Goldstein, C. E. Lyman and J. Zhang, in Microbeam Analysis-1990, J. R. Michael and P. Ingram, Eds., San Francisco Press, Inc., (1990), p. 265.

3. "Practical Importance of Spatial Resolution and Analytical Sensitivity in AEM X-ray Microanalysis", J. Zhang, D. B. Williams and J. I. Goldstein, in Microbeam Analysis-1990, J. R. Michael and P. Ingram, Eds., San Francisco Press, Inc., (1990), p. 307.

The papers accepted for publication are:

1. "The Structure and Composition of Metal Particles in Two Type 6 Ordinary Chondrites", C. E. Holland-Duffield, D. B. Williams and J. I. Goldstein, in press in Meteoritics.

The work statement for the third year of our present three year grant includes two major projects within an overall objective entitled, "Shock and Thermal History of Iron and Chondritic Meteorites". The work statement follows.

(NASA-CR-197143) SHOCK AND THERMAL HISTORY OF IRON AND CHONDRITIC METEORITES Progress Report (Lehigh Univ.) 9 p

N95-70356

Unclas

Z9/90 0030955

Work Statement Year Three (11 Months 4/1/91 - 2/28/92)

1. Formation of Metallic Phases in Meteoritic Metal Particles

We will use the combination of high resolution electron microscopy (HREM) and analytical electron microscopy (AEM) to characterize meteorite specimens and laboratory Fe-Ni and Fe-Ni-P alloys to examine the low Ni (<50 wt% Ni) region of the Fe-Ni phase diagram. Such information will allow us to understand how the clear taenite II, martensite and decomposed martensite (type III plessite) nucleate and grow at temperatures below 400°C in the high Ni regions of the metal particles. Further insights into the thermal history of meteorite metal can then be obtained.

In the third year of the study (4/1/91 - 2/28/92), we will use AEM to characterize the fine structure of Fe-Ni and Fe-Ni-P alloys, which have been heat treated at low temperatures (300-450°C). The structure of ultra-fine precipitates will be analyzed using a Philips 430 AEM. We will take advantage of new AEM instrumentation scheduled for delivery in fall 1991 to improve x-ray spatial resolution to <2 nm (20Å). A PhD candidate, Jing Zhang, with the assistance of Drs. D. B. Williams and J. I. Goldstein, will be responsible for this research. Mr. Zhang's thesis should be completed during the third year of this study.

2. Determination of the Thermal History of Chondritic Meteorites - Structure and Chemistry of the Metallic Particles

We will characterize the metallic particles of chondrites by AEM and electron microprobe techniques. Along with recent phase diagram results and complementary studies of plessite in iron meteorites, it should be possible to develop the low temperature thermal history of the metal particles and their host meteorites. Collaboration with the meteorite group of J. Taylor and E. R. D. Scott, at the University of New Mexico (University of Hawaii after 6/90), is crucial as both groups will work on the same meteorites and in many cases the same thin sections. The University of Hawaii group will study the silicates in order to delineate the high temperature parts of the thermal history of the chondrites. Initial emphasis will be placed on ordinary chondrites, types 3-6. We expect to develop, with the UNM group, thermal models for the individual chondrites which include both high and low temperature stages and are consistent with results of other techniques such as age dating from isotopic and track techniques. The project will be broken into two parts: a study of the fine structure in high metamorphic grade (5, 6) ordinary chondrites and a study of the fine structure in low metamorphic grade (3, 4) ordinary chondrites. The difficulty of understanding the structure and the thermal history of the metal particles will increase as the degree of reheating or metamorphism decreases and we envision developing more complex thermal models for the low metamorphic grade chondrites.

In the third year of the study, we will continue our investigations of metal particles in H and LL chondrites emphasizing electron optical techniques. The LL chondrites have larger amounts of Tetrataenite, ordered FeNi, and the H chondrites have larger amounts of metal. Specimen preparation of thin samples of metallic regions appropriate for electron microscopy has been particularly difficult and more emphasis will be placed on developing new thinning techniques. Image analysis of high resolution SEM images from bulk-opaque samples will also provide insight into these structures, and will be essential if thinning to electron transparency proves impossible. The H and LL samples will also be investigated by our collaborators. Thin sections for use in making analytical electron microscopy thin foils will be prepared in their laboratory. In addition, in a preliminary study, we will analyze by light optical microscopy and electron microprobe several carefully selected (by our collaborators at UNM) metal particles from sections of type 3 or 4 low metamorphic grade chondrites. Mr. Brian Pelton and a second Master of Science candidate, who will start graduate school in the spring 1991, will be responsible for this research. Drs. J. I. Goldstein and D. B. Williams will also be responsible for this research.

These tasks have been actively pursued during the present grant period although the third year of the grant does not begin until April 1, 1991. The following sections include a summary of the PI group achievements toward the objectives/tasks outlined above.

Project 1: Formation of Metallic Phases in Meteoritic Metal Particles

During the last year our electron microscopy studies of the plessite structure in iron meteorite specimens and our laboratory heat treatments and microscopy characterization of Fe-Ni and Fe-Ni-P alloys, with Ni contents from 15 to 45 wt%, were completed. Much of this research is summarized in an Abstract for the Lunar and Planetary Science Conference XXII, entitled "Investigation of plessite in iron meteorites and laboratory Fe-Ni(P) alloys" By J. Zhang, D. B. Williams and J. I. Goldstein. A copy of the Abstract follows this page. The results of this research form the basis of Mr. Jing Zhang's PhD thesis and are currently being written in the form of several technical papers. In the next few paragraphs, the most significant results of the research are summarized.

Plessite Structure in Iron Meteorites- Two types of g, taenite, precipitates are observed in the plessite of the octahedrites (Carlton and Grant). The first type of precipitate is formed at the original martensite lath/block boundaries and has a relatively large size (50 - 200 nm wide). The low Ni plessite regions (9-10 wt%) which have a coarse microstructure, called duplex plessite, are composed of these intergranular precipitates. The precipitates in the low Ni plessite regions have a 50 to 54 wt% Ni composition and have the $L1_0$ ordered fcc structure, tetrataenite. The matrix phase in the low Ni plessite regions has a bcc structure and a Ni composition of about 4-5 wt%. The second type of precipitate is formed inside the original martensite laths or plates along all crystallographically equivalent directions of the matrix. They are very thin plates or fine needles typically 10-20 nm wide. These intragranular precipitates are primarily formed in the plessite regions of high Ni content (>15 wt%), and therefore, the microstructure of the high Ni plessite regions is fine (black plessite). The precipitates in the high Ni plessite regions also have the $L1_0$ ordered fcc structure, however, they have a Ni content of 57 to 60 wt%. The matrix phase in the high Ni plessite region has a bcc structure and a Ni content of about 12 wt%. Both types of precipitates, intergranular and intragranular, are present in the plessite regions of 10 to 15 wt% Ni. In summary, the microstructure of iron meteorite plessite varies continuously with the average Ni content of the plessite region and have intergranular high Ni taenite precipitates at the low Ni end and intragranular high Ni taenite precipitates at the high Ni end of the plessite.

This complex plessite structure is a result of martensite formation and decomposition during the continuous cooling period. The transformations occured at different temperatures for the plessite regions of different Ni composition. The phase equilibrium of the low Ni plessite region is consistent with that measured at the Widmanstatten kamacite/taenite interface. The higher matrix Ni composition in the high Ni plessite region is due to the growth of the very fine precipitates which, by the capillary effect, require a matrix Ni composition higher than the equilibrium value for a planar interface. The high Ni content of the tetrataenite precipitates in the high Ni plessite is due to the fact that the ordering occured after the high Ni fcc precipitates were formed. The precipitate composition is >50 At% Ni below 300°C where the precipitates form.

Laboratory heat treatments and microscopy of Fe-Ni and Fe-Ni-P alloys- Laboratory alloys from 15 - 45 wt% Ni were heat treated in the temperature range 650°C to 300°C for time periods of 60 to 370 days. Intergranular precipitates are formed in the decomposed martensite alloys of 15 and 25 wt% Ni. The morphology of the precipitates in the 15 wt% Ni alloys decomposed at > 400°C is similar to that of the low Ni plessite of the octahedrites. Intragranular precipitates are formed in the decomposed martensitic alloys of 30 wt% Ni. The morphology of the precipitates in the 30 wt% Ni alloys is similar to that of the high Ni plessite of the octahedrites. The typical width

INVESTIGATION OF PLESSITE IN IRON METEORITES AND LABORATORY FE-NI(P) ALLOYS; J. Zhang, D.B. Williams, and J.I. Goldstein, Dept. of Materials Science & Engineering, Lehigh University, Bethlehem PA 18015, USA

Plessite in iron meteorites is a two phase structure with an fcc precipitate phase in a bcc matrix.[1,2] After Fe-Ni martensite forms during slow cooling, the martensite decomposition occurs at different temperatures. The morphology of the precipitates and the Ni content of both precipitate and matrix vary with the local average Ni composition of the plessite.

In this study, the plessite structure of two octahedrites, Carlton and Grant, was characterized using the analytical electron microscope (AEM). The composition of the taenite precipitates in various regions of plessite which have 9 to 13 wt% and 15 to 20 wt% Ni composition were measured using an x-ray energy dispersive spectrometer (EDS) in the AEM. To understand the phase transformation processes which occurred during the plessite formation, an experimental set of Fe-Ni binary and Fe-Ni-P ternary alloys were made and analyzed also using the AEM. The alloys, which have 15 to 30 wt% Ni (0.2 -0.3 wt% P for ternary alloys), were first homogenized at 1200°C and quenched to liquid nitrogen temperature to form martensite. They were then isothermally heat treated for 60 to 400 days in the temperature range from 450°C to 300°C. Two phase structures, which are similar to those of plessite, were formed in these alloys.

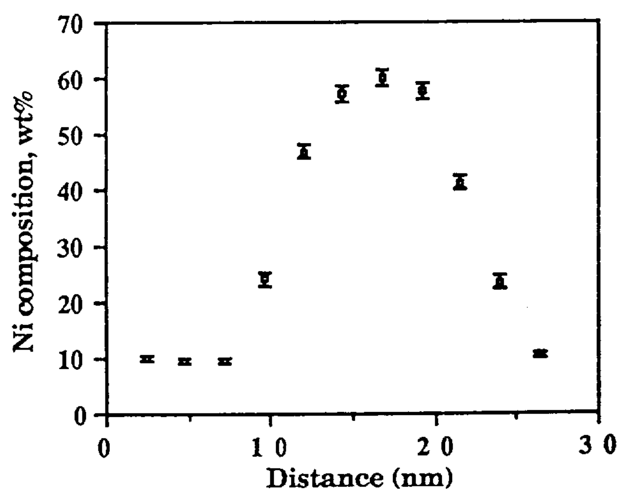
Two types of taenite precipitates are observed in the plessite region. The first type of precipitates is primarily formed at plessite regions of low Ni content (9~13 wt%). They are formed at the original martensite grain boundaries and have a relatively large size (50~200 nm wide). The precipitates in the low Ni region have a ~50 to 54 wt% Ni composition and are in equilibrium with a matrix phase of ~4 to 5 wt% Ni. The second type of precipitates is mostly formed in plessite regions of higher Ni concentration (15~20 wt%). They are formed inside the original martensite grains along all crystallographically equivalent directions with the precipitate {111} plane parallel to the matrix {110} plane. Their sizes are very small, typically 10~20 nm wide. The precipitates in the high Ni region have ~57 to 60 wt% Ni and are in equilibrium with a matrix phase of ~10 wt% Ni. Fig.1 shows an EDS Ni composition profile of a precipitate taken in an 18 wt% Ni region of the plessite of Carlton. Precipitate phases in both plessite regions in Carlton have the ordered fcc structure of Tetrataenite. However, precipitate phases in both plessite regions in Grant have a disordered fcc structure. This lack of the Tetrataenite phase in Grant is most likely due to the shock effect.

The microstructures of laboratory alloys have a similar morphology to that of the plessite regions of the same average Ni composition. Fig.2 shows TEM images of a 25 wt% Ni plessite region of the Carlton meteorite and a 30 wt%Ni alloy heat treated at 300°C for 370 days respectively. The precipitates are the dark platelets in the TEM images. The precipitates in the alloy have an fcc structure and no ordering is observed. This indicates that the ordering reaction is a much slower process than the martensite decomposition or the ordering temperature of FeNi is lower than 300°C rather than the reported 320°C. The compositions of the precipitate and the matrix of the alloy, measured using the EDS in the AEM, are ~57 wt% and ~21 wt% respectively. The microstructure of the alloy of 30 wt% Ni heat treated at 400°C is the same as that shown in Fig. 2 except that the sizes of the precipitates are larger (>50 nm wide) due to the higher diffusivity at the higher temperatures. The Ni composition of the precipitate and matrix in the 400°C alloy is ~50 wt% and ~8 wt% respectively.

The Fe-Ni phase equilibria measured in the decomposed martensite alloys can be used to explain the difference in Ni composition between precipitates in the high Ni and low Ni plessite regions. In the slow cooling process, the martensite is formed, and therefore, decomposed at relatively higher temperatures for the low Ni plessite region. In this region, the Ni composition of the precipitates increases gradually to ~50 wt% as cooling continues. The FeNi ordering transformation then occurs and stabilizes the precipitate composition at ~52 wt% Ni. In contrast, the martensite transformation occurs at lower temperatures in the high Ni plessite region. The precipitates formed by martensite decomposition at low temperatures have a Ni composition higher than 52 wt%. The FeNi ordering occurs after the precipitation and, therefore, the precipitates containing Tetrataenite have a Ni composition of 57 to 60 wt%.

The measured matrix composition in the low Ni plessite region is consistent with the current Fe-Ni phase diagram[3], however, that of the high Ni region is not. If we assume that the meteorites have enough time to reach equilibrium, the higher matrix Ni composition in the high Ni plessite region probably arises because of the effect of very sharp edge of the precipitate (<10 nm radius) on the local equilibrium composition, which termed Gibbs-Thomson effect[4]. The matrix Ni composition of the alloys is a complex function of the heat treatment. All compositions are higher than the predicted values in the phase diagram. In general, the lower the temperature and the finer the precipitates, the higher is the matrix composition. No significant composition gradient is detected to a spatial resolution of 2 nm. This indicates that the martensite decomposition process in Fe-Ni at low temperatures is interface reaction controlled. The much higher Ni composition of the matrix phase of the laboratory alloys is clear evidence that the heat treatment time is not long enough to bring the alloys to fully equilibrium.

REFERENCES: 1. L.S. Lin, D.B. Williams and J.I. Goldstein (1979) Geochim. Cosmochim. Acta **43**, 725. J. Zhang, D.B. Williams and J.I. Goldstein (1988) Meteoritics **23**, 314. 3. K.B. Reuter, D.B. Williams and J.I. Goldstein (1989) Met. Trans. **A20**, 719. 4. M. Hillert (1957) Jernkontorets Ann. **141**, 757.



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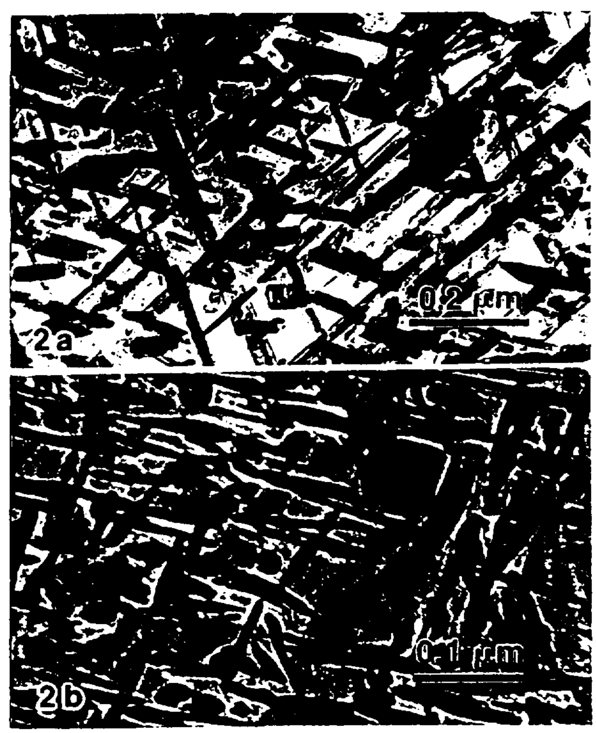

Fig.1 EDS Ni composition profile of a precipitate in an 18% Ni area of meteorite Carlton.
Fig.2 TEM images of a) a plessite region of Carlton meteorite, b) Fe-30wt%Ni alloy, 300°C for 370 days.

of the intragranular precipitates decreases from < 100 nm at 400^{0}C to 10 nm at 300^{0}C. The precipitates formed in all alloys have a fcc structure and no ordering is observed. This indicates that the FeNi ordering is a very slow process or the ordering temperature is lower than the previously reported value of 320^{0}C.

The phase equilibria of the Fe-Ni and Fe-Ni(P) system below 450^{0}C is formed by isothermal martensite decomposition. The Ni composition of the precipitates formed above 400^{0}C is consistent with that of the low Ni plessite regions in the iron meteorites. The Ni composition of the precipitates formed at low temperature (300^{0}C) is consistent with that of the high Ni plessite regions. The measured phase equilibria below 400^{0}C are metastable representing an intermediate state in the martensite decomposition. Finally there appears to be no significant difference in phase equilibria or in the morphology of the fcc precipitates between decomposed martensitic Fe-Ni and P saturated Fe-Ni(P) alloys heat treated in the temperature range 300^{0}C to 450^{0}C. The experimental work summarized above was discussed at a symposium on Materials Science of Magnetic Materials at the Annual Meeting of The Metallurgical Society, New Orleans in late February. A copy of the Abstract is given following this section.

Electron Microscopy - The study of plessite in octahedrites and of the microstructure of the heat treated Fe-Ni and Fe-Ni-P system involved a large amount of detailed analytical and conventional electron microscopy. Because of the need to analyze very small precipitates the PI group is continuously exploring ways to improve the compositional (x-ray) resolution of the analytical electron microscope. Two technical papers were written on this topic by the PI group and published in Microbeam Analysis - 1990. Both papers are given at the end of the Progress Report and were presented at the International Conference on Electron Microscopy in Seattle, August 1990. Mr. Zhang's paper was given a special student award by the Microbeam Analysis Society and was provided funds which enabled him to attend the meeting and give his paper.

Project 2: Determination of the Thermal History of Chondritic Meteorites - Stucture and Chemistry of the Metallic Particles

We have continued a study of the metal particles in chondrites in cooperation with Drs. Jeff Taylor and Ed Scott of the University of Hawaii. Our two groups agreed that we would examine in detail the fine structure of two unshocked group 6 chondrites, Kernouve (H6) and Saint Severin (LL6). Presumably, these meteorites have seen the highest reheating temperatures.

Ms. Catherine Duffield, who has completed her MS thesis, and the PI group have written a paper, entitled "The Structure and Composition of Metal Particles in Two Type 6 Ordinary Chondrites", summarizing the results of the research. This paper is now in press in Meteoritics. Among the most interesting results are 1) the discovery of three microstructural zones within the high Ni taenite (clear taenite) of both meteorites Kernouve and Saint Severin and 2) the observation of abnormally wide high Ni taenite regions bordering troilite which are probably caused by the diffusion of Ni from troilite into the high Ni taenite borders at low cooling temperatures.

One of the unexpected results of the metal particle study was the high magnification photomicrographs that were produced by the field emission SEM. Pictures at 50,000X and above were obtained which overlap the magnification range of the TEM. The field emission, high resolution SEM can eliminate the necessity for producing large numbers of TEM thin sections.

(11:10 a.m.)
MICROSTRUCTURAL AN
HIGH TEMPERATURE A_ . . .
F.E. Wawner, Department of Materials Science, University of Virginia, Charlottesville, VA 22903-2442.

There is a need for an aluminum-based material to replace titanium in high temperature aerospace applications. A P/M composite system of Al-9Ti reinforced with silicon carbide whiskers and particles was developed for this purpose. Microstructural and mechanical property evaluations of this system were performed to determine high temperature viability. Elevated temperature tensile tests produced strengths of better than 120 MPa at 500 C. Processing defects contributed significantly to failure at low temperatures; and these defects coarsened with prolonged high temperature exposure. Subsequent analysis has centered on relating the coarsening of the defects to the observed mechanical properties.

MATERIALS PROCESSING IN THE COMPUTER AGE V: MACROSCOPIC MODELLING OF SOLIDIFICATION PROCESSES, International Symposium

Sponsored by The Extraction and Processing Division and The Materials Design and Manufacturing Division of TMS

Wednesday, AM Room: Pontchartrain Ballroom C
February 20, 1991 Sheraton Hotel, 3rd Floor

Session Chairmen: Allon Brent, Central Research Laboratories, BHP Research and New Technology, Shortland, Australia;
Fred Bradley, Dept. of Mat. Sc. and Eng., University of Wisconsin-Madison, 1509 University Avenue, Madison, WI 53706

(8:30 a.m.) (KEYNOTE PAPER)
NUMERICAL MODELLING OF CASTING PROCESSES: PREDICTION OF AS-CAST MICROSTRUCTURE AND PREVENTION OF DEFECTS
L. KATGERMAN
Alcan International Limited, Banbury Research Laboratories, Banbury, Oxon OX16 7SP, U.K.

Computer modelling and simulation of fluid flow, heat flow and phase change, segregation and thermal stresses have been applied to improve understanding and performance of the various aspects of solidification and casting processes.

For the existing casting processes modelling can contribute to process optimization and quality control, where for novel solidification processes modelling can be an essential tool in the design of equipment and the evaluation of the process potential.

Examples will be given to illustrate the different approaches.

(9:10 a.m.)
A GENERAL NUMERICAL METHODOLOGY FOR MODELLING LATENT HEAT EVOLUTION DURING SOLIDIFICATION OF BINARY ALLOYS: C.R. Swaminathan and V.R. Voller, Mineral Resources Research Center, University of Minnesota, 56 East River Road, Minneapolis, MN 55455.

Much progress has been made in the field of numerical modelling of heat transfer in solidification systems of metallurgical importance. In many cases, however, models are restricted to a particular latent heat evolution mechanism. It is recognized that a truly general latent heat solidification method must be capable of handling a wide range of these mechanisms. In the present work, a general source based method is presented that has the capability of handling a wide range of latent heat evolution mechanisms. The method has been found to be robust and efficient. The method is illustrated on application to both one- and two-dimensional test problems.

(9:35 a.m.)
APPLICATION OF A FIXED-GRID SOURCE BASED METHOD TO MODELLING METALLURGICAL PHASE CHANGE SYSTEMS: A.D. Brent, Central Research Laboratories, BHP Research and New Technology, Shortland, Australia.

The application of a recently developed implicit source-based method for modelling solidification phase change is reported for three problems of practical metallurgical interest. The problem analyses vary in complexity, ranging from simple parabolic heat conduction models of the continuous casting of steel to a fully coupled heat transfer and fluid flow model of metal solidification in the ...e of natural convection. The method is robust, converges rapidly and ...y implemented in standard CFD codes. The results obtained from the ...odels are discussed and a verification to the accuracy of the method for modelling solidification in the presence of convection is made by comparing numerical predictions to experimental data available in the literature.

(10:00 a.m.)
Analysis of Fluid Flow and Melting Phenomena of Metal in a Cavity

B. Minaie

Ohio State University
Columbus, OH 43210

Abstract

A study of melting phenomena with fluid flow for metal in a cavity is carried out. The metal under consideration is gallium and the associated fluid flow during melting results from the presence of natural convection in the cavity. The study involves numerical investigation of the melting phenomena while convection and diffusion effects are present. The governing equations are solved using discretization scheme based on a volume element approach. The numerical treatment of melting is carried out using an enthalpy technique with the appropriate phase change terms on a fixed computational grid. The effect of natural convection flow on the evolution of the melting phenomena and the associated thermal fields are investigated. Comparisons are made with the available experimental data to validate the accuracy of the approach.

(10:25 a.m.) BREAK

(10:40 a.m.)
SPREAD SHEET MODEL OF CONTINUOUS CASTING: B.G. Thomas, Department of Mechanical and Industrial Engineering, University of Illinois at Urbana-Champaign, 1206 W. Green Street, Urbana, IL 61801.

Spread sheet programs provide a framework for very fast and easy development of simple engineering models. They are capable of relatively complex calculations that would require extensive effort using conventional fortran programming. The present paper describes a model of the continuous casting process that has been developed using a simple spread sheet program, Microsoft Excel, running on a Macintosh II personal computer. The model consists of 2D steady-state finite-difference heat conduction calculations within a continuous casting mold coupled to a 1D transient solidification heat transfer model of the solidifying shell. The model structure and equations are described and sample model results are compared with analytical solutions. practical examples using the model are discussed.

(11:05 a.m.)
Solidification Study of a Thin Walled Casting with Associated Fluid Flow

B. Minaie

Ohio State University
Columbus, OH 43210

Abstract

An investigation of the solidification of a thin walled casting in the presence of fluid flow is attempted. The associated fluid flow during the solidification is due to the existence of residual flow field resulting from filling the die cavity with liquid aluminum. The analysis involves numerical investigation of the solidification phenomena while taking into account this residual flow field and the diffusion through the die surfaces. Volume element method is used to solve the governing equations with the numerical treatment of solidification carried out by an enthalpy technique. The solidification patterns along with the shape of the solid-liquid interface are predicted while considering their evolution with respect to time. The effect of the residual flow field on the solidification patterns is investigated.

MATERIALS SCIENCE OF MAGNETIC MATERIALS II

Sponsored by the TMS Magnetic Materials Committee (EMPMD)

Wednesday, AM Room: Rosella
February 20, 1991 Sheraton Hotel, 4th Floor

Session Chairman: R.K. Mishra, Physics Department, General Motors Research Laboratories, Warren, MI 48090-9055

(8:30 a.m.)
CELL WALLS AS ANTIPHASE DOMAIN BOUNDARIES IN SM_2CO_{17} PERMANENT MAGNET ALLOYS, L. Rabenberg, Center for Materials Science and Engineering, The University of Texas, Austin, TX 78712-1063.

WEDNESDAY AM

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The two-phase, "cellular" microstructure in Sm_2Co_{17} permanent magnets is remarkable because its minor phase, $Sm(CoCu)_5$, forms as a precipitate from a $Sm_2(CoCuFe)_{17}$-based parent phase but ultimately becomes the only phase that is continuous in all three dimensions, even though it may comprise less than 10% by volume of the overall alloy. Although this microstructure is essential for coercivity and has been widely reproduced, there is no universally accepted paradigm for its formation. This paper emphasizes that the $Sm(CoCu)_5$ "cell walls" are interfaces between orientational and translational variants of the lower symmetry $Sm_2(CoFe)_{17}$ "cell interior" phase. As such, the cell walls are essentially antiphase domain boundaries coated by the disordered phase, and their continuity is a natural result of the topological constraint imposed by their included APB's. The anisotropy of the system, the mismatch between phases, and the two different orientational variants introduce some complications. Observations leading to this description of the cell walls will be presented and the implications of these ideas for the development and coarsening of the "cellular" structure will discussed.

(9:00 a.m.)

THE FORMATION OF POLYTWINNED STRUCTURES IN FE-PT AND FE-PD PERMANENT MAGNET ALLOYS: Z. Bing and W.A. Soffa, Department of Materials Science and Engineering, University of Pittsburgh, Pittsburgh, PA 15261

Fe-Pt and Fe-Pd alloys near the equiatomic composition undergo an ordering reaction cubic (A1) → tetragonal ($L1_0$) similar to the classic CuAuI ordering. In addition, the ordering transformation in Fe-Pt and Fe-Pd alloys is accompanied by the formation of a system of transformation twins producing a magnetically modulated structure. The tetragonal phase in the Fe-Pt and Fe-Pd systems shows a high uniaxial anisotropy ($K \sim 2\text{-}7\times10^7$ erg/cc) similar to the well-known Co-Pt alloys imparting to these materials interesting permanent magnet properties. In this paper the mechanism of formation of the polytwinned structures as revealed by transmission electron microscopy studies will be presented and the influence of the twinned structure on the magnetic domain structure and properties will be considered.

(This work is supported by the Department of Energy, Basic Energy Sciences, Materials Science Division.)

(9:30 a.m.)

GROWTH OF SINGLE CRYSTALS OF MAGNETOSTRICTIVE TB-DY ALLOYS: B. J. Beaudry, Ames Laboratory, Iowa State University, Ames, IA 50011, R. Doran, P.O. Box 1178, Milwaukee, WI 53201, E. Nevalainen, Ames Laboratory, Iowa State University, Ames, IA 50011.

Single crystals of Tb-Dy alloys up to 200 g have been grown by heat treatment of arc melted alloys. The dependence of the growth temperature on the composition of the alloys was determined. Second phase impurities were shown to have a detrimental effect on the growth of these crystals. Growth of seeded, oriented crystals by a float zone technique resulted in twinned crystals, probably due to the high temperature bcc phase present in these alloys. Heat treatment to remove the twins resulted in a new crystal orientation in the zone melted rod.

(10:00 a.m.) BREAK

(10:15 a.m.)

LOW TEMPERATURE METASTABLE PHASE EQUILIBRIA OF FE-NI ALLOYS: J. Zhang, D.B. Williams and J.I. Goldstein, Department of Material Science & Engineering, Lehigh University, Bethlehem, PA 18015.

The phase transformations of Fe-rich Fe-Ni alloys below 450°C were studied. The structure and composition of the decomposed martensite, with precipitates <20 nm wide, formed in long-term isothermal heat treatments were analyzed using analytical electron microscopy. The data were compared with the results from iron meteorites which are presumably the "ultimate equilibrium" Fe-Ni alloys. The $L1_0$ ordered FeNi phase found in meteorites was not observed in the laboratory alloys. The high Ni precipitate phase, however, had an fcc structure and a Ni composition of ~50 wt% at 400°C and ~56 wt% at 300°C. The Ni compositions of the matrix showed large differences from the equilibrium values predicted by the current phase diagram. A variation of the precipitate/matrix composition with temperature and the original martensite Ni content was observed. The influence of the magnetically induced miscibility gap on the martensite decomposition was also studied.

(10:45 a.m.)

PHASE EQUILIBRIA AND MAGNETIC PROPERTIES OF Fe-6.5wT.%Si ALLOY: K. Raviprasad and K. Chattopadhyay, Department of Metallurgy, Indian Institute of Science Bangalore-560012, INDIA

In the present paper we delineate the results obtained from a study of Fe-6wt.%Si alloy heat treated below the Curie temperature. The alloy, heat treated in single phase fields A2 and B2, is quenched into the two phase field B2 and DO_3. The microstructural evolution and the mode of transformations in isothermally heat treated samples are followed using TEM. The sizes of B2 and DO_3 ordered domains are measured. The domains are found to be isotropic in samples quenched from single phase field, whereas the domains are anisotropic in the samples heat treated below the spinodal temperature. The changes in the magnetic properties with the ordered domain size and the nature of APBs are discussed.

(11:15 a.m.)

IMPROVEMENT OF MAGNETIC PROPERTIES OF ELECTRICAL STEEL PLATES

T.Kumagai, T.Tomita and Y.Yamaba, Nagoya R&D Lab., Nippon Steel Corp., Tokai, Aichi, 476, Japan.

In recent years, demand for electrical steel plates has been growing substantially in such areas of application as material for magnet poles for large particle accelerators and for magnetic shields for magnetic resonance imaging (MRI) and so forth.

Electrical steel plates for MRI and other magnetic shields, in particular, are required to possess further improved magnetic properties (permeability) for the purpose of reducing material weight through enhancing the shielding effect. To enhance the shilding effect, it is necessary to increase the magnetic flux density in areas where magnetizing forces are as low as 80A/m or less. To meet this requirement, manufacturing conditions for electrical steel plates have been studied, with particular emphasis on the chemical composition and the rolling conditions. This study has clarified the following contributing factors affecting magnetic properties.

(1) Up to magnetizing force levels of some 20A/m, the magnetic induction is virtually determined by the grain size.
(2) The magnetic flux density at magnetizing force levels near 80A/m does not necessarily correspond to the grain size and is more susceptible to the grain orientation or the texture.
(3) The more and closer the grain orientation in the directions of (100) and (110) are aligned to normal direction rather than in the derections of (111) and (211), the greater the tendency toward the enhancement of the magnetic flux density at a magnetizing force level of 80A/m.
(4) The improvement of magnetic properties of electrical steel plates obtained by the addition of Si is combined effect of coarser grains and the aligned texture.

MICROCOMPOSITES AND NANOPHASE MATERIALS III: Microcomposites

Sponsored by TMS Physical Metallurgy Committee

Wednesday, AM	Room: Mardi Gras Balcony I-J
February 20, 1991	Marriott Hotel, 4th Floor

Session Chairman: Gary S. Was, Dept. of Materials Science and Engineering, The University of Michigan, Ann Arbor, MI 48109 - 2136

WEDNESDAY AM

(8:30 a.m.)

DEFORMATION MODELING OF MICROLAMINATED MATERIALS, A. K. Ghosh, C. Kang and J. Holmes, University of Michigan, Departments of Materials Science and Engineering and Mechanical Engineering, Ann Arbor, MI 48109

The deformation of a thin band of metallic material bonded to parallel ceramic laminates has been examined using continuum mechanics approaches. The contraints imposed by the hard ceramic phase has been calculated for the cases of a rigid, as well as an elastic, reinforcement. The matrix has been considered to be elastic-plastic and strain hardening. Extremely high levels of hydrostatic stresses are found to develop within the matrix as the laminate thickness becomes smaller. The significant restriction to plastic flow of the matrix leads to strengthening in addition to conventional composite strengthening effects. Insight is obtained into the prevailing stress states at the laminate interfaces, for which no data exists currently. Results of computation for metal/metal microlaminates will also be presented.

(9:00 a.m.)

ULTRAFINE SUPERSTRENGTH MATERIALS

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Naval Research Laboratory, Washington, DC 20375-5000
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A theory on superstrength materials has been developed by Louat. This theory rests on the fundamental assumption that materials with exceptional strength can be obtained by embedding a high volume fraction (50% or greater) of ultrafine particles (preferably nanometer size) in a ductile matrix or alloy. In contrast to conventional alloys, these materials retain most of their strength even when the matrix melts. In this paper we will review Louat's theory on superstrength and present the experimental results obtained at the Naval Research Laboratory in studying and developing superstrength materials. The experimental results obtained thus far are consistent with the predictions of theory on superstrength.

(9:30 a.m.)

STRONG HIGH-TEMPERATURE ALLOYS

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The following statements will be amplified and substantiated. With certain provisos the strength of two

Lehigh will install its new JEOL 6300F field emission SEM this spring (1991) and we will employ this instrument in our metal particle studies. In addition, we expect to install our new Vacuum Generators 300 kev field emission analytical electron microscope this fall (1991). This instrument in combination with suitable thin sections of meteoritic metal particles should enable us to obtain a compositional (x-ray) resolution of 2.5nm or better.

Unfortunately, the preparation of the metal particles in ordinary chondrites for transmission electron microscopy has proved to be very difficult. After a major effort by Ms. Duffield to produce adequate thin sections, only two successful samples were thinned. In the last grant period, we continued to be unsuccessful. One MS student, Mr. Brian Pelton, was unable to produce the required samples and we brought his research to a premature conclusion. Another student who started at Lehigh in the fall of 1990 dropped out of graduate school after only one month. A third student, Mr. C. W. Yang, with an excellent background in TEM began working on the grant in January 1991. At this time we are cautiously optimistic with regard to producing adequate samples. With these samples, we expect to determine the composition and crystal structure of the metal particles in group 6 ordinary chondrites and to use these data to help us understand the development of the unusual fine structure in the clear taenite region of the group 6 metal particles.